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Water Production from Atmospheric Air Using a Solar Water Recuperator by Glass Pyramid Device

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Abstract: The present research examines the effect of the pyramid solar system's shape, notably the multi-bed pyramid, on the system's ability to gather water from the ambient atmosphere. In this research, a solar collector in the shape of a prism pyramid with 4 glass walls was designed and constructed. The collector stood at a height of (140 cm). The insulating layer at the pyramid's base was 15 cm thick, and its base was 100 cm × 100 cm. Thick panes of glass line the sides of the two pyramids (5 mm). The pyramid's interior included five levels of storage. Each shelf was about (20 cm) vertically apart. Each pyramidal unit's bed thickness is (10 cm). Saw wood and cloth were used as hosts in the collection process, and the calcium chloride ($CaCl_2$) solution is used as a moisture absorber. Moisture was taken in from the atmosphere at night. During the day, solar energy evaporates the water that has been absorbed, and the water vapor condenses on the edges of the solar collector. The experimental findings demonstrated the potential to achieve an average water productivity of (1.25 L/day/m^2) of surface area. The results also demonstrated that the pyramid coated with the $CaCl_2$ solution-soaked cloth performed better than the other glass pyramid by roughly 5% on average daily in June 2022. It was deduced that this rise was caused by more $CaCl_2$ solution being collected.

Keywords:
Water Production; Absorption; Desiccant material; Pyramid Device; Regeneration.

Highlights:
- *Solar glass pyramid yields 1.25 L/day/m^2 water from atmospheric air.*
- *Cloth-based $CaCl_2$ outperforms sawdust by 5% in moisture absorption.*
- *Multi-shelf design boosts condensation efficiency via solar regeneration.*
- *Higher solar radiation directly increases water productivity by 25%.*

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إنتاج الماء من الهواء الجوي باستخدام مُسترجِع مائي شمسي بواسطة جهاز هرمي زجاجي

حسين حيدر محمد علي، سعاد حسن دانوك، خديجة عمر محي الدين
قسم تقنيات ميكانيك القوى / الكلية التقنية الهندسية - كركوك / الجامعة التقنية الشمالية / كركوك - العراق.

الخلاصة
يتناول البحث الحالي تأثير شكل النظام الشمسي الهرمي، ولا سيما الهرم متعدد الطبقات، على قدرة النظام على جمع المياه من الغلاف الجوي المحيط. في هذا البحث، تم تصميم وبناء مجمع شمسي على شكل هرم منشوري بأربعة جدران زجاجية. يقف المجمع على ارتفاع (١٤٠ سم). كانت الطبقة العازلة عند قاعدة الهرم بسمك ١٥ سم، وكانت قاعدتها ١٠٠ سم × ١٠٠ سم. تبطن ألواح زجاجية سميكة جوانب الهرمين (٥ مم). تضمن الجزء الداخلي من الهرم خمسة مستويات للتخزين. كان كل رف متباعدًا رأسيًا بحوالي (٢٠ سم). يبلغ سمك فراش كل وحدة هرمية (١٠ سم). تم استخدام الخشب المنشور والقماش كمضيفين في عملية التجميع، وتم استخدام محلول كلوريد الكالسيوم (CaCl2) كممتص للرطوبة. تم أخذ الرطوبة من الغلاف الجوي ليلاً. خلال النهار، تُبخِّر الطاقة الشمسية الماء المُمتص، ويتكثف بخار الماء على حواف المُجمّع الشمسي. وقد أظهرت النتائج التجريبية إمكانية تحقيق متوسط إنتاجية مياه يبلغ (١,٢٥ لتر/يوم/متر مربع) من مساحة السطح. كما أظهرت النتائج أن الهرم المُغطى بقطعة قماش مُبلّلة بمحلول كلوريد الكالسيوم (CaCl2) كان أداؤه أفضل من الهرم الزجاجي الآخر بنحو ٥٪ يوميًا في المتوسط في يونيو ٢٠٢٢. وقد استُنتج أن هذا الارتفاع ناتج عن جمع المزيد من محلول كلوريد الكالسيوم.

الكلمات الدالة: إنتاج المياه، الامتصاص، مادة التجفيف، جهاز الهرم، التجديد.

1.INTRODUCTION

One of the most pressing problems facing developed and developing nations is providing of clean drinking water. Although there is an abundance of water on the planet, the uneven distribution of these resources has created a dire shortage. In addition, water efficiency is inconsistently practiced in settings as diverse as agriculture, manufacturing, and domestic life. At present, a water problem is affecting a considerable number of nations [1-3]. They cannot exist in the absence of water. The freshwater supply makes up only 2.53 % (or 35 million kilometers) of the planet's entire (1.384 billion kilometers). Permanent ice and snow cover a generous portion of the Antarctic and Arctic, providing most of the freshwater supply (24 million cubic kilometers). Freshwater lakes and rivers cover roughly 0.26 % of the world's total clean water reserves (90,000 cubic kilometers) [4]. The water content of the atmosphere is vast and replenishable. Throughout the planet, this limitless supply of water can be accessed. The process of obtaining water from the air has several benefits. It is estimated that there is only around (1,200 cubic kilometers) of clean water in the globe, making the air a renewable and pure water supply [5].
About (14,000 cubic kilometers) of steam water can be found in the atmosphere [6], making it a potential new and sustainable water supply. Water can be extracted from the air in two different ways:

- Cooling the air to a temperature less than its condensation point.
- Absorbing the steam from the air with a solid or liquid desiccant, and then recovering the water by heating the drier and condensing the water vapor.

The engineering community must consider things like investment, operation, and energy prices in addition to regional climate when deciding which approach to consider. However, patented systems range in size and quantity of drinkable water from modest units suited for one person's daily requirements to constructions as big as multi-story office buildings capable of delivering water supply to an urban area [7]. Extracting moisture using ethylene glycol as a desiccant and solar distilling was proposed by Hall [6]. A composition-psychometric table detailing the results of an analysis of temperature and relative humidity was provided; however, the amount of water gathered is left unstated. Moist air was gathered by Alayli et al. [7] using a normal S-shaped chemical substance that was then regenerated using solar energy. The process of solar still involves heating the liquid component with solar rays. Evaporation and condensation yield (1.0 liter) of drinkable water per square meter of composite material. Gad et al. [8] used a solar water recuperator to extract moisture from the air using a combined (solar/desiccant) system. The vapor condenses throughout the day, replenished the desiccant at night. To maximize mass transfer, beds were constructed from many layers of densely corrugated material soaked with $CaCl_2$. A fan was used to move air around the bed area at night. A condenser was also required. The process was repeated twice without the condenser. Using the condenser device resulted in a 5% drop in overall system efficiency. The overall output was (1.5 L/day m^2). By putting a solar collector on a bed of sand, Kabeel [9] could harvest atmospheric moisture for later use. Theoretical and practical tests were conducted to determine the efficacy of a sand bed soaked with a 30% $CaCl_2$ solution in producing water from humid air. The system potentially produced about (1.2) liters of water per square meter of glass covers daily. Three inclination angles (15, 20, and 25) were used to assess the system's robustness. Using a multi-shelf solar system atop a glass pyramid, Kabeel [10] studied the feasibility of harvesting water from the humid atmosphere. Beds of all shapes and sizes lined the shelves of two pyramids. The beds were filled with a calcium chloride ($CaCl_2$) solution at a 30% concentration. At night, the sides of the pyramid were opened to let in humid air, while during the day, they were closed to keep the sun's rays out and dry the bedding. The bed in the first pyramid was built from sawn wood, while the bed in the second pyramid was constructed entirely out of cloth; however, it was the same size. It was subjected to a wide range of conditions in an experimental setting to assess the system's ability to absorb and regenerate. Preliminary results showed that a fabric bed can absorb (9 kg) of the solution; significantly more than a bed made of saw wood (8 kg). This method consistently yields (2.5 L/day m^2) daily. The new system's output was increased by 90–95% over the old one (sandy bed solar collector system). The cloth bed method was more effective than the traditional saw wood bed. Under the effect of solar radiation, Ji et al. [11] used an adsorbent composite to extract humid air. The ultra-large pore crystalline material MCM-41 was combined with calcium chloride ($CaCl_2$) (hygroscopic salt) to develop a novel category of selective liquid compound adsorbents. Unique composites can absorb up to 1.75 times their dry weight. It performed better than calcium chloride ($CaCl_2$) and silica gel-based composites. In some cases, even at temperatures as low as (80 °C), more than 90 % of the adsorbed water can be desorbed. More than 1.2 kilograms of water per square meter per day was produced daily. Hamed et al. [12] designed, built and evaluated an experimental desiccant/collector solar regenerator in Taif, Saudi Arabia. This desiccant uses a calcium chloride ($CaCl_2$) solution. Experiments and data analysis suggest that when the solution concentration is adjusted with night conditions, over 30% of fresh water can be recovered on each square meter using a solar-powered desiccant system with a sand bed. The method has been proven more effective in the Al-Hada region, where the dew point is higher than in Taif City. Using a compound desiccant material called "$CaCl_2$/ Saw wood," Kumar and Yadav [1] studied water formation from ambient in Indian weather conditions. CaCl2 content in wood has been shown to affect the water production rate. It was found that the highest rate of water production was (180 ml/kg/day). Findings suggested that raising the saw wood's calcium chloride ($CaCl_2$) content can raise available water. William et al [13] proposed water extract from ambient air as a revolutionary renewable energy technique. The mechanism extracted moisture from the air at night. Throughout the day, they can have simultaneous desiccant regeneration and water vapor condensation. A trapezoidal prism solar collector is made up of four fiberglass faces. This collector's (desiccant absorber) multiple shelves, increasing its effective surface area. So, the area available for evaporation and absorption was increased. All the operating modes detailed their respective regeneration and absorption procedures. Moreover, calcium chloride solution undergoes testing on a wide range of substrates (including cloth and sand). The total amount of water evaporated from the cloth and the sand bed, using $CaCl_2$ at a saturation concentration of 30%, was determined to be 2.32 and 1.23 liter/day m^2, respectively. The success rate of the sand method was only 17.76%, while the cloth system only had a success rate of 29.3%. Kumar et al. [14] investigated the feasibility of using a desiccant-based solar recuperation system to collect potable water from the air. Orange silica gel was used as a desiccant to remove moisture from the air overnight. The water was reclaimed from the silica gel-covered bed using solar recuperation during the day. This method has been found to economically produce 0.98 L/day of potable water. The purpose of this study is to study the performance and efficiency of the multi-shelf hierarchical solar system used to extract water from atmospheric air.

2.THEORETICAL ANALYSIS

2.1.The Amount of Water Extracted from the Atmosphere

The productivity of water leaving the atmospheric air per hour can be calculated from the following formula [10]:

$$M_W = (\omega_{out} - \omega_{out}) \times m_a \tag{1}$$

where:

ω is the percentage of humidity or moisture content of the air that can be calculated from [15, 17]:

$$\omega = m_v/m_a = 0.622 \times p_v/p_b - p_v \tag{2}$$

m_a is the mass of dry air, measured (kg/sec), can be calculated from:

$$m_a = \frac{p_a v_a}{R_a T} \tag{3}$$

where:

p_a is the partial pressure of dry air, measured in (kPa).

T is the air temperature measured in (°C).

R_a is the gas constant for dry air, and its value is (0.287 kJ/kg.K).

v_a:is the volume flow rate measured in (m^3/sec) and can be calculated from [15, 18, 19]:

$$V_a = \frac{Ra\, T}{p_b} \tag{4}$$

where:

p_b is the atmospheric pressure, and its value is (1.01326 bar)

2.2.The Amount of Water Extracted from the Atmosphere

The amount of moisture absorbing material for each of the shelves in the device can be calculated from [12, 20]:

$$M_S = x * M_{Sol} \tag{5}$$

where:

M_{sol} is the mass of the solution can be calculated from [10, 21, 22]:

$$M_{Sol} = M_s + M_W \quad (6)$$

x is the concentration of the solution can be calculated from [6]:

$$x = [ln(pv) - (a_0 - b_0/(t + 111.96))]/(a_1 - b_1/(t + 111.96)) \quad (7)$$

where:

pv is the water vapor pressure, measured in mm H_g, and can be calculated from [6]:

$$M_{Sol} = M_s + M_W \quad (8)$$

$$ln(pv) = A(x) - \frac{B(x)}{t + 111.96} \quad (9)$$

where:

$B(x)$ and $A(x)$ are the concentration-dependent parameters and can be expressed as a linear function of x [6]:

$$A(x) = a_0 + (a_1 x) \quad (10)$$

$$B(x) = b_0 + (b_1 x) \quad (11)$$

where:

$ao, a1, bo, b1$: are the regression constants, and their values are as follows [6]:

ao = 10.0624, a 1 =4.4674, bo =739.828, and b1 =1450.96

x is a variable range with a value ranging from (0.2 – 0.5) [6].

2.3.System Efficiency

The efficiency of the system can be calculated from [16, 23-26]:

$$\eta = \frac{P_{out}}{P_{in}} = \frac{M_W L}{(\Gamma_\alpha) H A} \quad (12)$$

where:

M_W is the amount of water extracted from the air per hour.

L is the latent heat measured by (J/kg)

H is the solar radiation intensity measured in (W/m^2)

A is the surface area measured in (m^2)

r_α is the product of absorbance and transmittance.

3.EXPERIMENTAL APPROACH

3.1.Description of the System

A solar water recuperator system has a pyramid shape with four glass sides and a square base. It was used in the present experimental work, as shown in Fig. 1. The external test bench's pyramidal construction was composed of an aluminum frame to prevent corrosion during use. The pyramids' sides were made entirely of glass (5 mm thick). A plate shaped like a letter frame decorated the perimeter of any glass cover (V). Five steel wire shelves of diameter were housed inside the pyramid (5 mm). It is worth noting that the shelves inside were empty and folded up in the steel corners. The passage of condensed steam was allowed. Nails and screws were used to fasten the fiberglass shells to an aluminum framework. To stop steam from escaping, a rubber was placed between the pyramid's glass sides and its steel base. The pyramid was (140) cm tall, its base insulation was (15) cm thick, and its dimensions were (100 cm × 100 cm). The inside of the pyramid consisted of five levels. The distance between each shelf in the vertical direction was (20 cm). The wheeled design made transporting the multilevel structure simple. The presnt work involved the construction of two mechanically and dimensionally identical units. The base of each shelf in each tier is saturated with a solution of moisture-absorbent calcium chloride ($CaCl_2$) to prevent moisture buildup, with sawdust and cloth used as additives for CaCl2. During the night, the glass sides of the pyramids open, allowing moisture from the surrounding air to be absorbed by the base of the shelf. As soon as the morning passed and the day began to warm up, the sides of the pyramid were closed off again. The pyramid's glass sides allow solar radiation to enter the structure, increasing the temperature inside the structure and, in turn, evaporating any moisture absorbed at the base of the shelf. The pyramid's top was where the droplets formed from the condensation of the steam that had risen to that level. A part of this vapor will additionally condense on the interior surface of the pyramid's side walls. Condensed water droplets were gathered in a glass basin, which also functioned as a container for storing water if it was not required. The base was skewed ever-so-slightly toward its center to ease the condensate accumulation at this location. The experimental system was installed in Kirkuk, Iraq (35.46˚N latitude and 44.38˚E longitude).

Fig. 1 A Photographic of a Multi-Shelf Solar Pyramid.

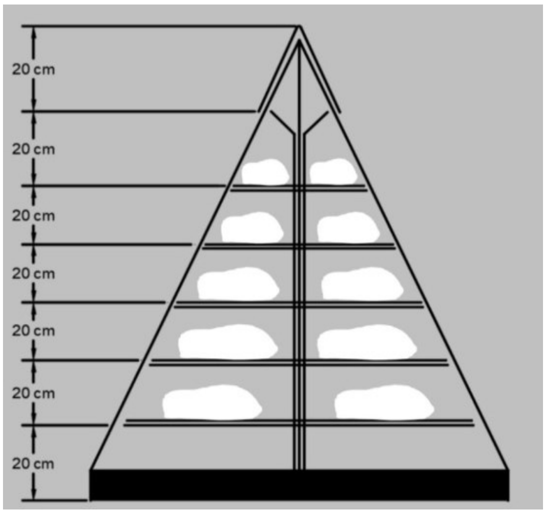
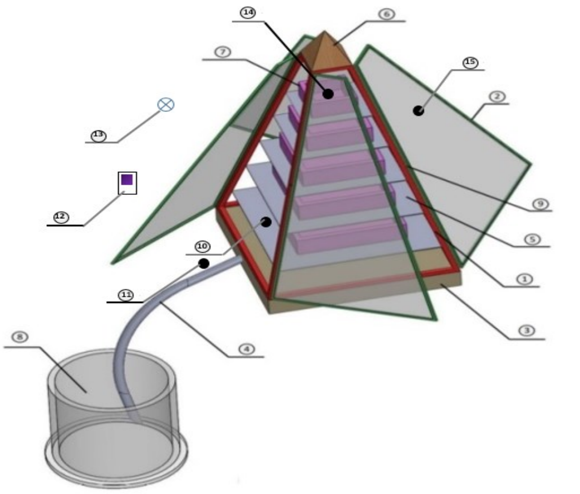


Fig. 2 A Schematic Diagram of a Multi-Shelf Solar Pyramid.



No.	Part name
1	Pyramid sides
2	Glass cover
3	Pyramid base
4	Collected water
5	Bed
6	Collected cone
7	Shelves
8	Graduated glass
9	Glass support
10	Inside temperature and relative humidity meter
11	outside temperature and relative humidity meter
12	Solar radiation intensity meter
13	Wind velocity meter
14	Glass temperature meter
15	Shelf base temperature meter

Fig. 3 Open-Topped Pyramid Made of Glass at Night.

3.2.Measuring Devices

Measurements were used to measure atmospheric conditions (temperatures, relative humidity, wind velocity, and solar radiation intensity). Instrument types, resolution, accuracy, and uncertainty of calculation are listed in Table 1.

Table 1 Instrument Types, Resolution, Accuracy, and Uncertainty.

Instruments	Type	Resolution	Accuracy	± *Unceratainty*	%
Temperature	Thermocouple type - K	0.10 °C	±0.2%	±0.293°C	1.4%
Relative humidity	Tes-1367	1%	±0.5%	±1.1%	2.56%
Wind velocity	DA40	0.01 m/s	±0.75%	±0.13 m/s	2.4%
Solar radiation intensity	Tes-1333	0.1 W/m²	±0.39%	±5 W/m²	3%

3.3.Experimental Procedure

The experimental procedure included the following steps:

1- After sunset, the four sides of the pyramid were opened, and then the moisture absorbent material ($CaCl_2$) was placed on each of the shelves in the device.
2- The four sides of the pyramid were closed after sunrise.
3- Readings were taken from 8:00 AM until 5:00 PM at every hour during the day.
4- Temperatures at various positions (on the cover glass of the four ends of the pyramids, shelf base temperatures, and atmospheric temperature) were measured.
5- Solar radiation intensity and wind speed were measured.
6- The relative humidity at various positions (inside and outside the pyramids) were measured.
7- The amount of water collected was measured at 1-hour intervals.

4.RESULTS AND DISCUSSIONS

The present study presents the results from the practical experiments installed in Kirkuk, Iraq (35.46°N latitude and 44.38°E longitude). The experiments were conducted on the solar collector with a pyramidal, multi-layered shape over June 2022 with a solution of calcium chloride with different additives (cloth and sawdust) by studying the behavior of the system during the day and evaluating it under different operating conditions (effect Atmospheric conditions, the effect of the difference in the concentration of moisture absorbent material at the base of the shelf, the effect of the difference in total water productivity, and the effect of the difference in the efficiency of the solar collector). The results are presented by drawing the graphs using the Excel program, and the absorption and regeneration processes are discussed for each case in the following sections:

4.1.The Impact of the System's Daytime Weather Conditions

Solar radiation falls on the absorber plate, then radiated heat is taken in by the base of the shelf, increasing the shelf's base temperature and the surface vapor pressure. The evaporation process primarily depends on the weather conditions throughout the day, as water evaporates due to the difference in vapor pressure between the shelf's base surfaces and the glass surfaces. The maximum value of solar radiation was (897.3 W/m² in June) at midday, as shown in Fig. 4,with the air temperature variation throughout the same period (1:00 PM) because the sun's rays are nearly perpendicular to Earth's surface during midday, producing a higher solar radiation level. The outside temperature gauge follows the sun's path throughout the day because the sun's rays primarily determine the air temperature. At midday in June, the temperature outside increased to (38.3 °C).

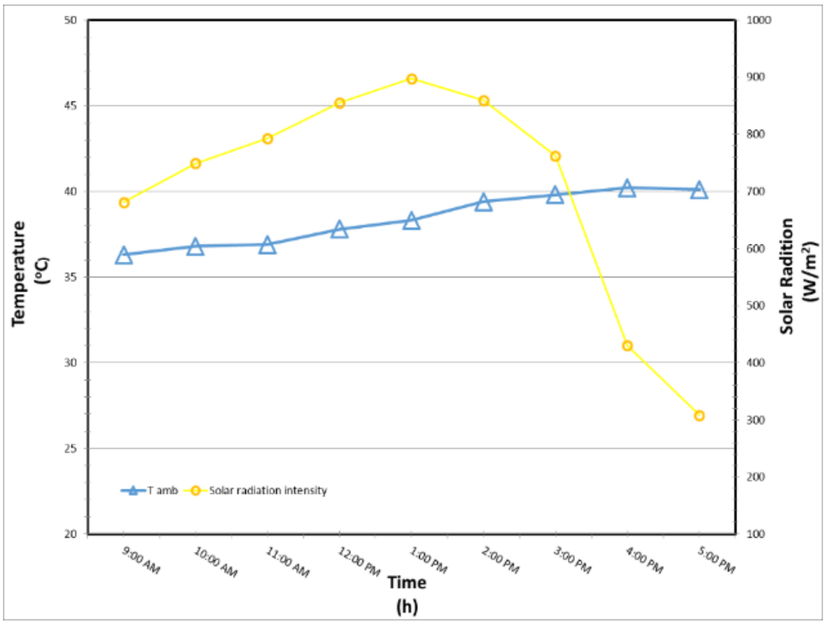


Fig. 4 Variation of Air Temperature and Solar Radiation with Time on 18/6/2022, Kirkuk, Iraq.

Figure 5 depicts a time-variant temperature dissimilarity between the inner surfaces of the four sides of the cover glass. The side cover's temperature will change depending on its position with respect to the sun. The southern and northern faces serve as the system's front and back panels, respectively. Since solar radiation fell continuously on the southern (front) side of a building from dawn to dusk, its temperature was often higher than on the other sides. The back cover's (the northern side) temperature was lower than the other sides because it received less solar energy and was thus subject to the same fluctuations in the air temperature. The system's east and west were indicated by the east and west surfaces, respectively. With the sun's rays hitting the eastern side from dawn till midday, the temperature increased significantly. The midday solar radiation decreased, making the western side hotter than the other sides, while the western side's high air temperature and large thermal storage heated it more than the other sides. Different surfaces experienced different condensation rates at hours of the day. Since the north cover (back side) was the coldest part of the system, it was where the condensation rate was highest. Condensation occured quickly near the collector's top because the steam was drawn upward by the buoyancy of the water vapor.

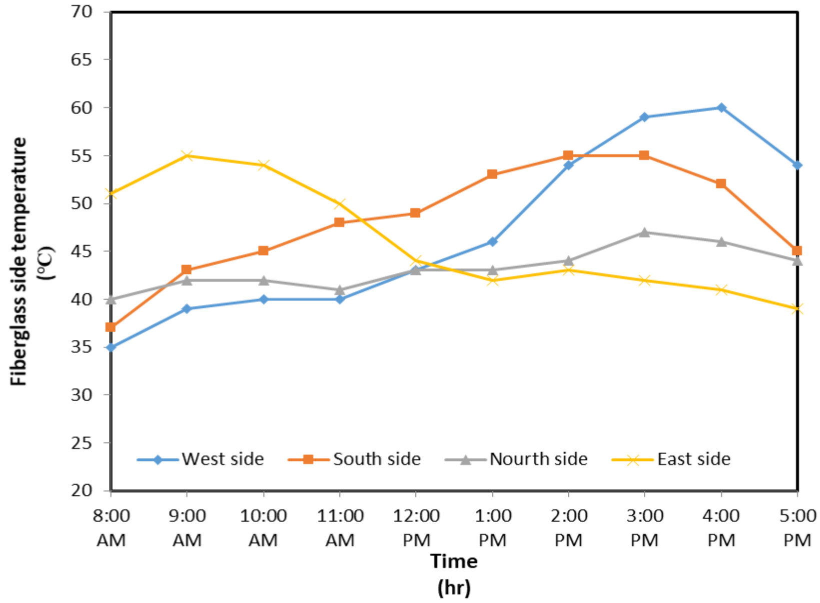


Fig. 5 Variation in the Temperature of the Internal Surfaces of the Glass Cover with Time On 18/6/2022, Kirkuk, Iraq.

Figure 6 displays the range of temperatures at the base of each shelf as a function of the amount of incident solar radiation absorbed. Because of the heat capacity of the shelf base, it follows the same pattern as the solar radiation curve, but the peaks were in the evening. It is interesting to note that the bottom tier had a different temperature from the upper, middle, and lower shelves. The heat capacity of the shelf foundation, the amount of shadow, and the total shelf surface area all contribute to this variation. Having the most mass and hence the most heat capacity, the lower shelf's base temperature was the coldest because the middle shelf casts a shadow on the bottom. Since more sunlight can reach the larger surface area of the intermediate shelf, its temperature is slightly greater than the upper shelf. The reduced heat capacity of the bottom of the rack caused the base of the top rack to be the highest on some days. June's peak upper, middle, and lower shelf temperatures were (63.5°C, 66.7°C and 55.2°C), respectively.

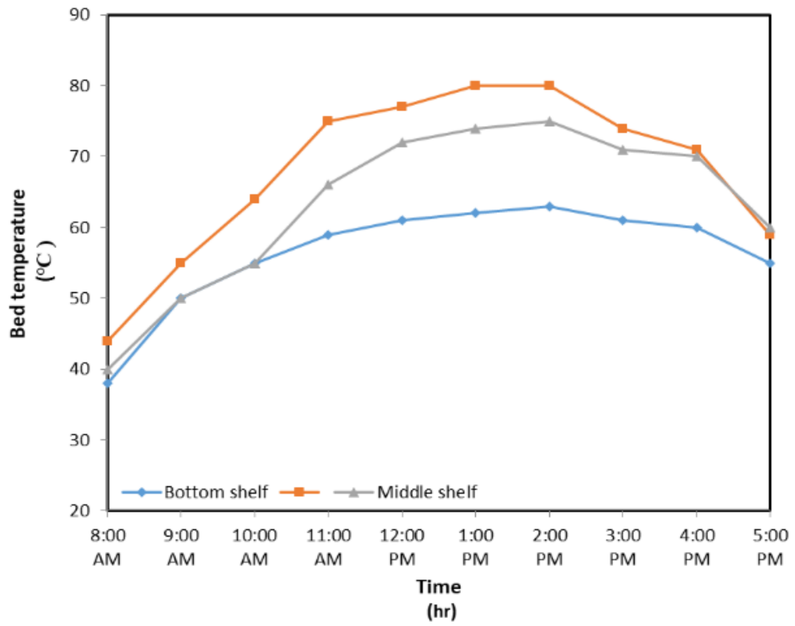


Fig. 6 Variation of Temperature for Each Shelf Base with Time on 6/18/2022, Kirkuk, Iraq.

Figure 7 shows a the difference between the relative humidity and temperature of the air and inside the device over time. It is noted that the maximum air temperature reached (39.4 °C in June) and the temperature inside the device (54.1 °C in June) at (5:00 PM), while the relative humidity value of the atmosphere decreased (11% in June) and inside the device (8% in June) in the afternoon. The relative humidity inside the device was less than the relative humidity in the atmosphere, due to the absorption of moisture by the absorbent material, and the elevated temperature inside the device, because the temperature is inversely proportional to the relative humidity. The higher the air temperature, the lower the relative humidity, and vice versa.

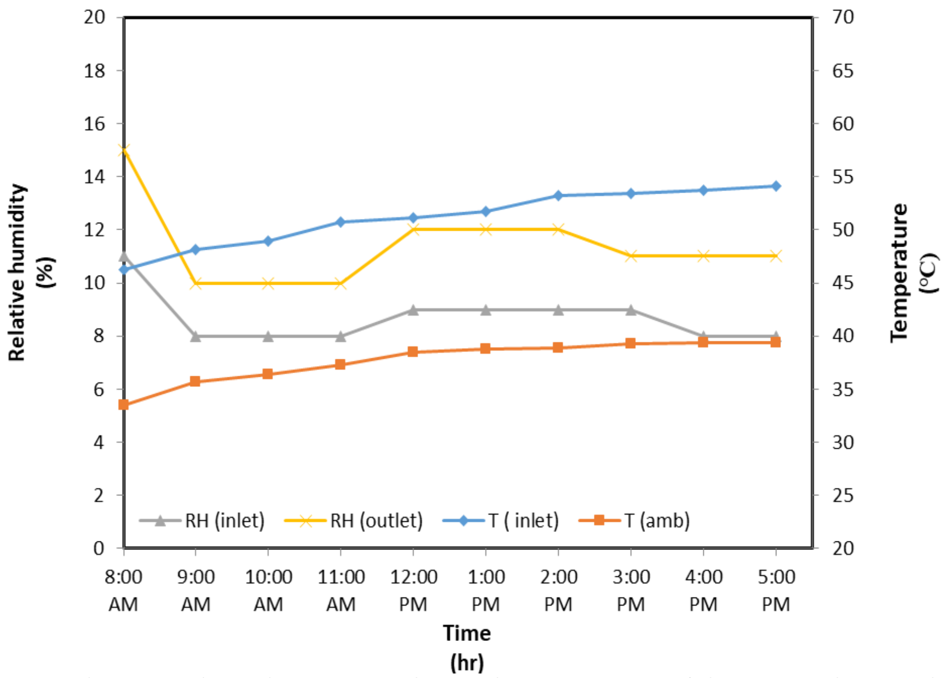


Fig. 7 Variation between the Relative Humidity and Temperature of the Atmosphere and Inside the Device with Time on 6/18/2022, Kirkuk, Iraq.

4.2.The Effect of Varying the Concentration of the Moisture-Absorbing Material at the Base of The Shelf

At the beginning of the experiment, there was a minimum difference in the concentration of the absorbent moisture with time (in the morning). The moisture-absorbing substance in the shelves was concentrated more heavily on the first day of the experiment than on the second, as seen in Figs. 8 and 9. 6/15/2022 was the first day of experimental activity, and the moisture-absorbent material concentration at the top shelf's foot was shifted from (30% to 53%). On 6/16/2022, the concentration differential between the shelf base and the upper layer shifted from (33% to 54%). Changes in solar energy, air temperature, and wind speed from day to day resulted in variations in the initial concentration.

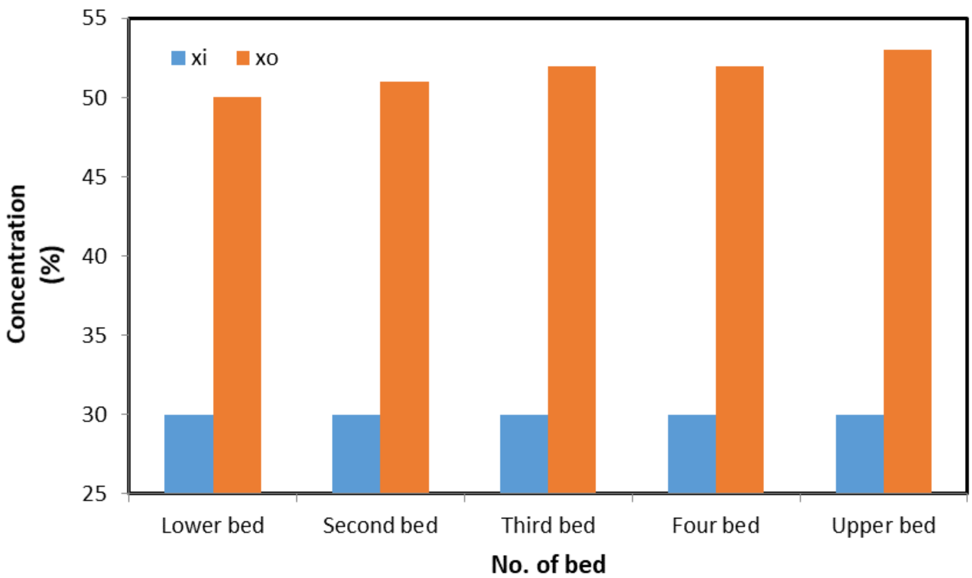


Fig. 8 The Difference in the Concentration of the Moisture-Absorbent Material at the Shelf's Base with Time on 15/6/2022 (During the First Day of the Experimental Work).

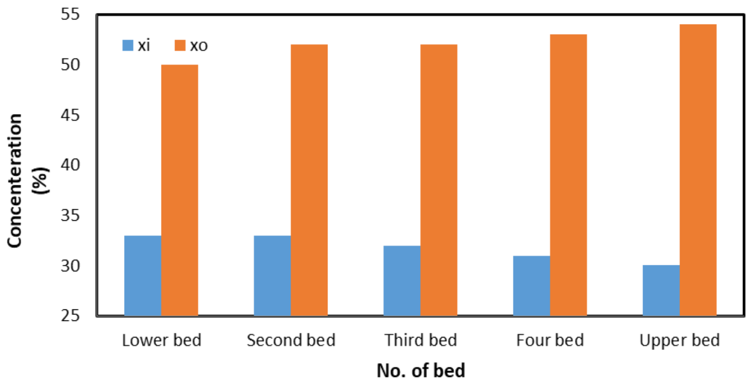


Fig. 9 The Difference in the Concentration of the Moisture-Absorbent Material at the Base of the Shelf with Time on 16/6/2022 (During the Next Day of the Experimental Work).

4.3.The Effect of the Difference in the Total Water Productivity of the System

Figure 10 shows the variation of water productivity with time for the city of Kirkuk, Iraq. The rate of water collected increased over time to a maximum value in a certain period in the afternoon and then decreased gradually. Water productivity depends on the air temperature. Whenever the air temperature decreased, evaporated water's condensation from the moisture-absorbing materials on the glass cover increased. Thus, the condensed water collects in the water collector container. Likewise, the decrease in the air temperature increases the relative humidity in the atmospheric air and vice versa. Water condensed on the glass cover due to the elevated temperature of the medium because the atmospheric air uses a cooling medium to cool the glass cover, which leads to vapor condensation inside the device on the inner surface of the glass cover. Figure 10 compares the practical results and researchers of water productivity from moist air with time for Kirkuk City, Iraq. To show the effectiveness of this system in the present study, it was necessary to compare its productivity, which is the average productivity per day (1.25 L/day/m^2). It is noted that the maximum value of productivity was from (2:00 PM) due to the increase in solar radiation falling on the test device, which leads to irritation of the moisture-absorbing material and the absorbent water evaporates from it, and then the productivity decreased gradually due to the high temperature The air temperature inside the cover glass decreasd the concentration of the absorbent. Compared with Ref. [12], the water productivity was about. (1 L/day/m^2). Compare with Ref. [10], it is noted that the amount of water produced was about (2.5 L/day/m^2) due to the high solar radiation. The change in water productivity was due to the relative humidity. The higher the relative humidity, the higher the water productivity, and vice versa. Figure 11 shows the variation of total water produced from moist air with time during the day. It is noted that the values increased gradually from (8:00 AM) until they reached their highest value at (5:00 PM). Water production varied from day to day because of variations in factors like ambient conditions, solar radiation, wind velocity, and the concentration of hygroscopic materials near the shelf's base. Figure 11 compares the experimental results and researchers of the total water generated from moist air with time for Kirkuk City, Iraq. It is noted in all cases that the value of the total water increased from (8:00 AM) until the highest value was reached at (5:00 PM). The total daily productivity of the present work was (1.25 L/day/m^2) with an increase of 25% over the productivity of the researcher in Ref. [12], whose value was (1 L/day/m^2). While the daily productivity of the researcher in Ref. [10] is about (2.5 L/day/m^2), with an increase of 1.25% over the present work, whose value was 1.25 L/day/m^2).

4.3.The Effect of Varying the Efficiency of the Solar Collector

Figure 12 shows the difference in system efficiency with time for Kirkuk City, Iraq. It notes that its value increased from (8:00 AM in wintry weather) and with time, the moisture-absorbing material gradually heated due to the increase in solar radiation falling on it as it approached noon, which leads to evaporation of the absorbed moisture by the absorbent material. Efficiency is a reason for the high air temperature, leading to a rise in thermal storage in the atmosphere, negatively affecting the cooling of the glass cover and reducing the amount of water vapor condensed on the glass cover, and in turn the productivity decreased. Therefore, efficiency gradually decreased, as the relationship between efficiency and productivity was a direct. Figure 12 compares the experimental and researchers' results of the system's efficiency with time for Kirkuk City, Iraq. If it is noticed that the highest efficiency was by Ref. [10], then the efficiency of the present study and the lowest efficiency was by Ref. [12], the reason is due to water productivity, where the relationship of water productivity is direct with the efficiency of the system, the more productive the more water the more efficient and vice versa.

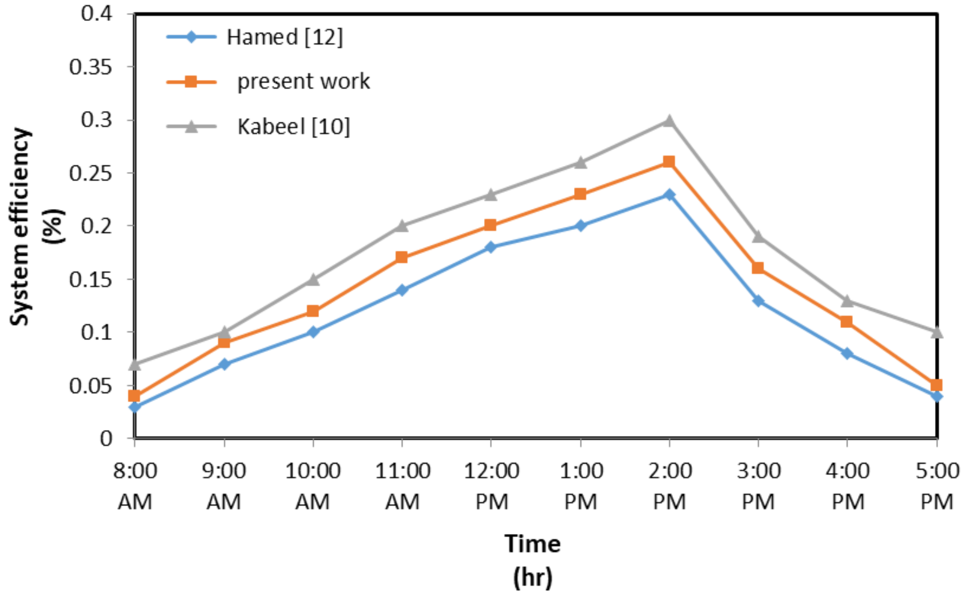


Fig. 10 A Comparison between the Experimental Results and Researchers of the Water Productivity Resulting from Moist Air with Time on 18/6/2022, Kirkuk, Iraq.

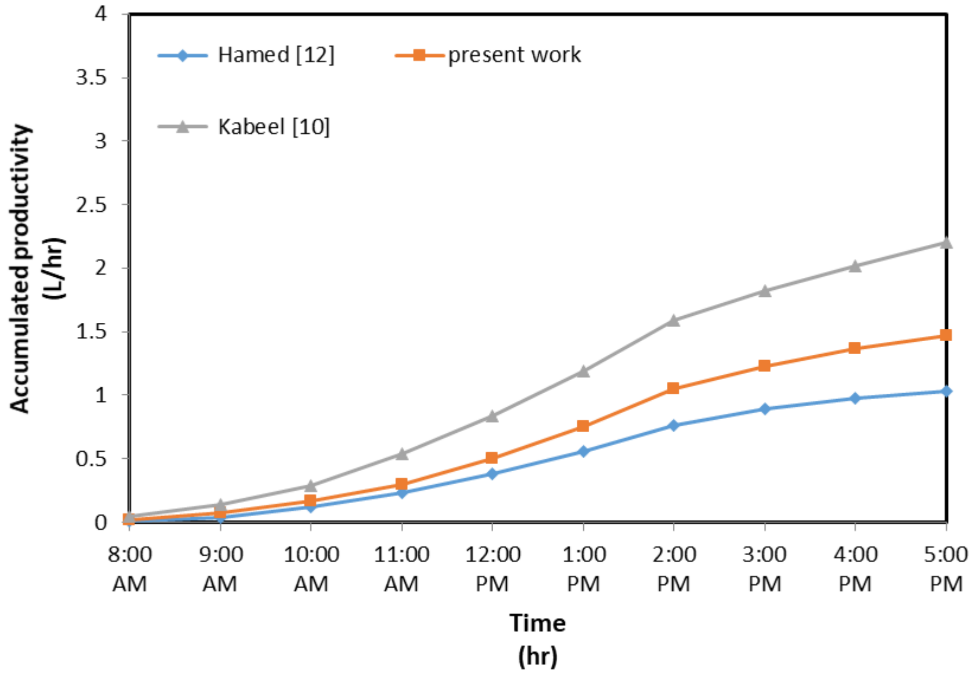


Fig. 11 A Comparison between the Experimental Results and Researchers of the Total Water Generated from Moist Air with Time on 18/6/2022, Kirkuk, Iraq.

5.CONCLUSIONS

Using a solar pyramid collecting system, the present study successfully distilled water from the surrounding air. Calcium chloride was employed here to prevent moisture buildup. System operation included opening all four sides of the pyramid at night to draw moisture from the air. When the four walls were sealed during the day, the desiccant wasn regenerated, and water vapor can condensed. The following crucial conclusions were drawn from experiments conducted on bright, sunny days outside:

1- Daily water production from atmospheric humidity averaged 1.25 L/day/m².
2- The highest water productivity was in August, where it reached (0.3 L/hr), followed by July, where it reached (0.25 L/hr), and the lowest productivity is in the month of June, where it reaches (0.23 L/hr).
3- The higher the intensity of solar radiation, the higher the water productivity and system efficiency, and vice versa.
4- The system's efficiency was directly related to productivity; the higher the productivity, the greater the efficiency of the system, and vice versa.
5- A glass pyramid containing cloth was mre efficient than a glass pyramid saw-wood because the amount of solution absorbed at

the beginning of the experimental work was greater than that of the shelf containing sawdust.

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NOMENCLATURE

A	Surface area, m²
H	Solar radiation intensity, (W/m²)
L	Latent heat of water, (J/kg)
T	Air temperature, (°C)
P	Power, (W)
p	Pressure, (Pa)
x	Concentration of the solution moisture
ω	Content of air or humidity ratio, (kg/kg_{air})
Greek symbols	
η	System efficiency, %
Abbreviation	
$CaCl_2$	calcium chloride
Subscripts	
a	ambient
s	salt
sol	solution
v	vapor
in	inlet
out	outlet

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